Science, Scholarship and the Communication of Knowledge

F.W. LANCASTER
LINDA C. SMITH

THIS PAPER EXPLORES THE major channels by which research results are disseminated, with special reference to the role played in this communication process by libraries and other formal information centers, identifies some of the problems existing within these channels, points to some significant recent advances in the dissemination of research information, and suggests some possible future trends.

The most important channels by which the results of research and application activities are disseminated in science and other fields are depicted at the macrolevel in Figure 1. The box headed "User Community" includes two components: those individuals who are involved in (1) research and development and (2) the application of the results of research and development. The communication problem represented in this diagram is that of disseminating the results and experience of research, development and application activities rapidly and efficiently to those individuals who need and can profit by this information.

As the diagram shows, various members of the "user community" report the results of their research and development activities or of their experiences in some field of application. These reports can be written or oral. Much of this information is disseminated in a completely informal way. Information is exchanged by individuals through correspondence and by conversations, either face-to-face or by telephone. Some of this information when assimilated stimulates new research or applications.

F.W. Lancaster is Professor, and Linda Smith is Assistant Professor, Graduate School of Library Science, University of Illinois at Urbana-Champaign.

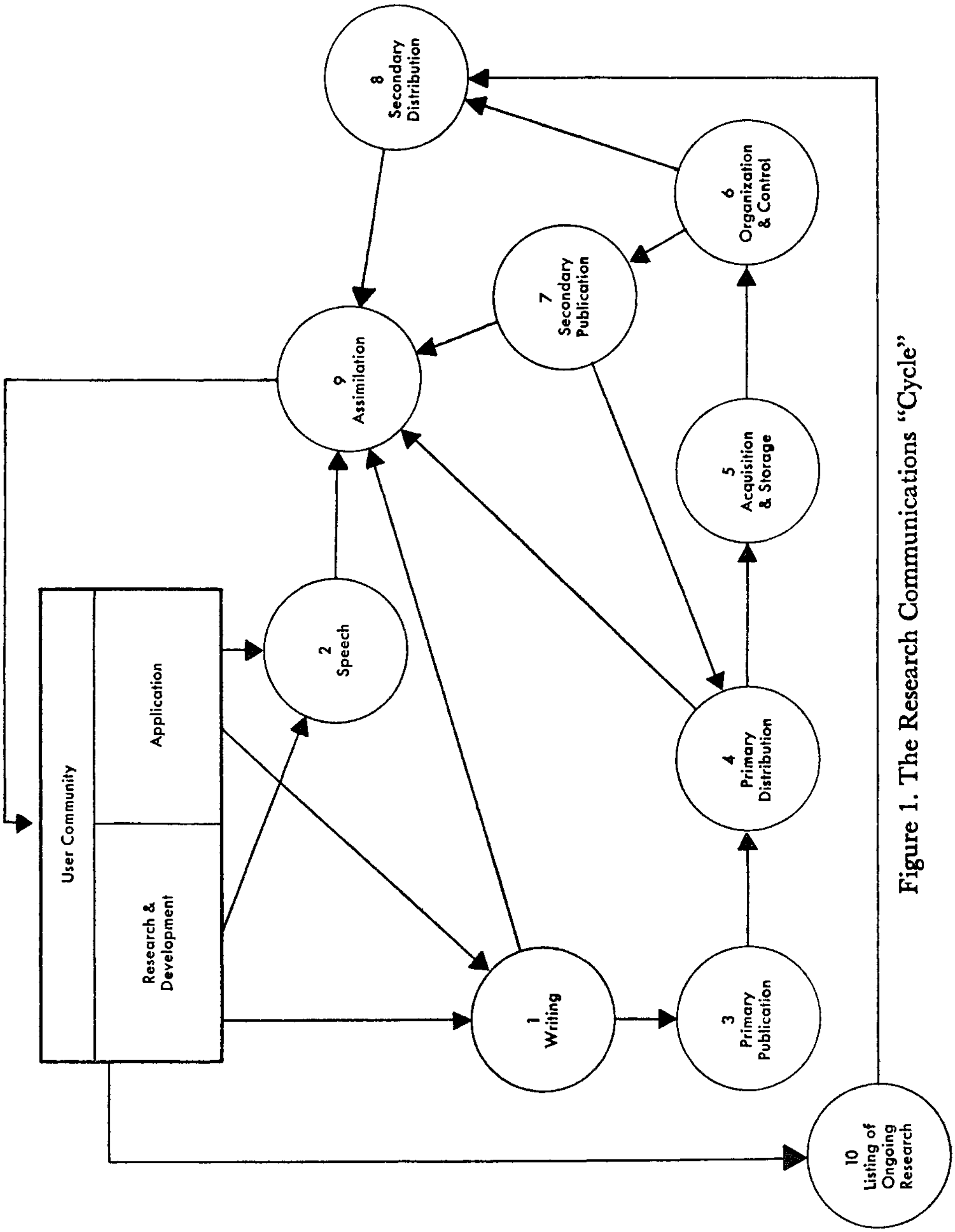

Figure 1. The Research Communications "Cycle"

These new projects generate their own reports which in turn are disseminated. The communication process represented in the diagram is thus a continuous and regenerative cycle. Science could not survive without an efficient communication cycle to support it.

The informal channels of communication are represented by the paths of one to nine and two to nine. The other paths, all leading eventually to the "assimilation" activity, represent the formal communication channels. In practice, however, the distinction between formal and informal communication is not as clear-cut as suggested in the diagram. Some channels combine both elements. An obvious example of this is the professional conference. Papers presented at such a conference, whether published or not, are formal communications, while the informal exchange through conversations in hotel lobbies, bars and restaurants is clearly informal. Moreover, formal communications may be disseminated through informal channels, as when a scientist mails a reprint of a periodical article to several of his professional colleagues.

As depicted in the diagram, many individuals and organizations play various roles in the distribution of information in written form. Writing does not in itself constitute communication. A message must be received before communication takes place. Publishers of primary and secondary literature fulfill a primary distribution function as well as a publication function. Some primary publications and a few secondary ones are distributed directly to the user community through purchase and subscription by individuals. Much of this literature, however, reaches its users through secondary distribution functions performed by libraries and other information centers. These institutions play extremely important roles in the cycle. They have the prime responsibility for acquiring the published literature, for storing it (thus creating a permanent archive of scientific achievement), for organizing and controlling it, and for its secondary distribution. The secondary distribution activities of libraries and information centers include all services provided: document delivery services, literature searching, and reference services of all types, including services provided from machine-readable data bases.

Another path in the communication cycle, and one that has assumed increasing importance in the last few years, is that by which information on ongoing research is disseminated through formal channels. Although some indexes to ongoing research are issued in printed form, the major source of this information in the United States is the Smithsonian Science Information Exchange, which provides services on demand from its machine-readable data base. This path is therefore considered primarily as one of secondary distribution.

The communication cycle has not always looked exactly as depicted in the diagram. While informal communication channels in some form are as old as science itself, other channels are much more recent in origin. For all intents and purposes, primary publication dates back only to the invention of the printing press, but the major primary publication of science, the periodical, emerged only in the latter half of the seventeenth century, and secondary publications in science began to appear only in the nineteenth century. Indexes to ongoing research are a twentieth-century development. The configuration of the cycle, then, has changed over the years and can be expected to change further in the future. New communication channels emerge, others decline in importance and eventually disappear. As one example, the distribution of secondary publications directly to the user community is now almost nonexistent and there is evidence to suggest that the primary distribution of the science journals directly to the user community is declining relative to their secondary distribution through libraries.

As long as science itself continues to grow, all of the communication activities of the cycle must also increase at approximately the same rate. Price has pointed out that every time the world population doubles, the world population of scientists doubles about three times.[1] There is little evidence that the limits to growth of science have been reached, although there may now be some leveling-off in the rate of growth among the most developed nations. For example, King and others have estimated that the scientific and engineering labor force in the United States increased by 64 percent in the decade from 1960 to 1970, but by only 12 percent from 1970 to 1975. They project a further growth of 14 percent from 1975 to 1980.[2] However, while the growth of science may be reaching a plateau in the developed countries, scientific activity is increasing at a very rapid rate in the developing world. As one example, Unesco statistics indicate that there were 156,000 scientists and engineers in Argentina in 1965 and 390,000 in 1974, which represents an increase of about 150 percent in nine years.[3] According to *Science Indicators,* the number of scientists and engineers engaged in research and development activities per 10,000 population declined in the United States after 1969, but continued to increase in the other countries studied.[4] In 1973 this figure was twenty-five in the United States, eighteen in West Germany, nineteen in Japan (1971 data) and thirty-seven in the USSR.

SCIENCE INFORMATION SOURCES

The literature of science is often divided into two types of publications:[5] (1) primary, which report the results of research and application; and (2) secondary, which are compiled from primary sources and arranged according to some definite plan. Secondary publications provide access to the primary literature (e.g., bibliographies) and/or condense information from the primary literature (e.g., reference books).

The historical development of formal communication channels based on the distribution of primary and secondary publications cannot be considered apart from the development of science and the community of scientists, because for a long time scientists themselves were the major determinants of innovations in scientific communication. More recently, however, channels have evolved due to outside influences, particularly government and technology.

From the time of the invention of printing to the latter half of the seventeenth century, the only way new scientific ideas could be made public was through specially printed and published books.[6] Science was a very different enterprise from that which is known today — research was almost entirely an amateur activity for a few well-educated or intellectually curious individuals with other means of support. As their numbers increased, savants (as scientists were called) formed academies to discuss research and perform experiments. One of the first such groups was the Royal Society of London, founded in 1662. These academies became centers for the communication of scientific knowledge and were responsible for a major innovation — the scientific journal, beginning with the *Philosophical Transactions* of the Royal Society and the *Journal des Sçavans* of France's Académie Royale des Sciences.[7] Initially these journals contained book reviews, scientific news and observations, and translations of letters from foreign scientists. In the eighteenth century journals were general in their coverage, but in the nineteenth century, with the growing number of scientists working in specialized areas, journals devoted to particular areas of science emerged.

The character of the scientist has changed dramatically in 300 years, from mainly amateurs in the seventeenth and eighteenth centuries to academic professionals beginning in the nineteenth century (the term *scientist* was coined in 1840) and the industrial research scientists of the twentieth century. Yet the science journal remains as the most important primary publication form. A recent development is the letters journal, made up of short communications for rapid dissemination of preliminary results of research, designed to overcome the time lag typical of most journals. The emergence of letters journals indicates that the journal as a communication medium is not without problems, more of which will be addressed later.

As the primary literature of science grew, there was a need for another communication innovation. The original purpose of journals was not to publish new scientific papers so much as to monitor and digest the learned publications and letters that were too much for one individual to cope with in daily reading and correspondence. In turn, when the number of journals grew too large for one person to monitor, the abstract journal emerged in the 1820s under the sponsorship of individuals and professional societies.[8] Just as the early journals were general in their coverage, early abstract journals were polymathic, with discipline-oriented abstracting services emerging later. The abstract journal can serve both functions of a secondary publication, since it includes citations to the primary literature as well as condensations of article contents. As the volume of scientific literature grew, two other kinds of secondary publications were developed to perform these functions separately. The index, beginning in the latter half of the nineteenth century, provided access to primary literature by arranging citations in subject categories. The review journal, which emerged in the twentieth century, provided evaluation and synthesis of an increasingly fragmented literature.

All of the developments described so far can be viewed as "of science" in the sense that the community of scientists had primary responsibility for their initiation and support. These developments are the predecessors of the discipline-oriented information systems sponsored by many professional societies today, with their journals, abstracting services, monographic series on research topics of special interest, and reference books such as data compilations.

The impact of government on scientific literature can be seen in the mission-oriented information systems of the federal agencies which have grown rapidly since World War II in such areas as defense, aeronautics and atomic energy. The major type of publication handled by these is the technical report describing research supported by grants and contracts from the government.[9] As government expenditures for research and development have multiplied, so have the number of technical reports issued and, not surprisingly, there are now a number of abstract journals with the sole purpose of covering the technical report literature. Since technical reports contain much information which will be reported in the journal literature only at a later date (or never), they have emerged as an important primary source.

The publications described above, whether sponsored by professional societies or government agencies, do not differ radically in form from the early printed publications. The advent of the computer and machine-readable data bases has changed this, however, as can be seen from the following examples which may be thought of as the beginning of an "automated reference library":

1. bibliographic data bases — abstracting and indexing services in machine-readable form remove many of the search constraints of printed tools. Citations may be retrieved based on sophisticated search strategies including terms from the title and abstract as well as controlled vocabularies.
2. numerical data bases — the printed handbooks and tables of data are being replaced by numeric data base systems which allow not only retrieval of specific data items, but also their manipulation. The data are used directly in simulation models, statistical analyses, or to create graphic displays.[10]
3. directories — directories of very current information are feasible when the data are stored in machine-readable form. Two examples, one from the basic sciences and one from the applied, illustrate existing services:

   Smithsonian Science Information Exchange (SSIE) — contains notices of more than 200,000 ongoing research projects from which selected project notices are retrieved in response to specific requests. Each item in the data base is a notice of a research project — who is conducting what research where, under whose support and when.[11]

   Technotec — a service designed to bring together those who search the data base and originators of entries so that technology can be exchanged. Entries in the data base include notices of technology for sale in the form of know-how, products, licenses or specific services and notices of technology needed.[12]

While the computer has to date affected the way in which secondary publications are used, in time a transformation of primary publications may appear as well, with the development of "electronic journals," central data bases containing articles that can be accessed by individuals through remote terminals.

SCIENCE INFORMATION SERVICES

A discussion of the development of science information sources must be coupled with an identification of the services provided by institutions involved in secondary distribution. For with the growth and increase in cost of the literature, personal collections can encompass only small portions of the available literature. While the scientific societies accumulated libraries from the seventeenth century onward and libraries have long been associated with academic institutions, these functioned primarily as storehouses. The concept of information services is most closely associated with special libraries. Although the term *special library* embraces special libraries and special collections of many types, the strength of the special library movement has come from the rise in number of libraries serving business, industry and government.[13] The pattern of development of these libraries, beginning in the 1870s in chemical, pharmaceutical and engineering firms, was similar in both Britain and the United States.[14] Their chronological development was characterized by:

1. gradual accumulation of books and journals by the research staff;
2. part-time supervision of the collection by members of the research staff;
3. introduction of a full-time librarian when the stock became unusable through size or disorganization; and
4. organization and dissemination of information by local indexing, routing of periodicals, compilation of bibliographies and abstract bulletins, production of translations, and completion of literature searches.

Libraries traditionally acquire, store, organize and index, and make materials available. As Kruzas observed, the early special libraries were distinguished for "simultaneously neglecting and extending the standard library practices of their time."[15] Special librarians did so in pursuit of their particular goal: library service geared to the program of their parent organization and to the information needs of its personnel. They acquired more diverse types of materials than other libraries, supplementing the traditional books and periodicals with patents, blueprints, maps and company laboratory reports. They stored material only so long as it was useful and then discarded it. When they found standard methods of organizing material inadequate, they developed "homegrown" classification schemes which allowed organization of materials in relation to company interests and analysis of content in greater depth. All this was directed toward the goal of making information available efficiently. In summary, the special library "movement" of the late nineteenth and early twentieth centuries can be characterized by: (1) use of all forms of recorded information as practical tools, (2) limitation in coverage of resources to material related to the work of the parent organization, and (3) expansion and extension of reference services as a principal function of the library. This emphasis is captured in the motto "putting knowledge to work," adopted by the Special Libraries Association soon after its founding in 1909.

The services offered today do not differ substantially in kind from those described by special librarians early in this century. Perhaps the major new development is an exploration of ways in which librarians can participate more actively in the teams which have become the mode of work for much science research and application. In medicine one now finds clinical medical librarians accompanying medical teams on rounds;[16] a similar approach in industry would involve the librarian as the "information expert" on project teams.[17] In both environments the objective is to exploit existing information resources better; the librarian gathers data relevant to specific questions that arise in the work environment.

Special libraries originally developed with an emphasis on service to business, industry and government. While government special libraries continue to be important, there are two other areas in which the federal government has contributed to the development of science information services: the national libraries and information analysis centers.

The National Library of Medicine (NLM) and the National Agricultural Library (NAL) were originally organized to serve specific federal agencies, but through government support they have grown into research libraries of international stature with a diversity of products and services used throughout the world.[18] They have published catalogs, indexes, bibliographies and, more recently, machine-readable data bases. Each library is the pinnacle of a library-based network of document delivery services. NAL works with land-grant colleges and NLM works with designated regional and resource medical libraries to facilitate interlibrary loan.

The national libraries strive for comprehensive coverage in their designated areas of responsibility. Government-sponsored information analysis centers (IACs), on the other hand, are established with a view to supplying specific services tailored to the needs of an elite clientele involved in an advanced and often multidisciplinary area of research and development.[19] While a few information analysis centers were established in the nineteenth and early twentieth centuries, their greatest increase occurred following World War II. Two examples are the Metals and Ceramics Information Analysis Center and the Nondestructive Testing Information Analysis Center, both associated with the U.S. Defense Logistics Agency. The intent of IACs is to transfer to the user timely, authoritative and evaluated information in a convenient form.[20] They employ subject specialists to prepare such products as state-of-the-art reports, critical analyses and current awareness bulletins, and to answer queries requiring extensive time and subject expertise.

Federally sponsored information services, whether provided by special libraries, national libraries or information analysis centers, thus include: (1) production of machine-readable data bases; (2) publication of abstracting, indexing and announcement services; (3) literature search services; (4) document supply services; (5) research in progress services; and (6) creation of numeric data bases.[21] They are all a manifestation of the government policy with respect to scientific communication, recently reaffirmed in the National Science and Technology Policy, Organization and Priorities Act of 1976, which states that it is the responsibility of the federal government to promote prompt, effective, reliable and systematic transfer of scientific and technical information by appropriate methods.

Government funds, used both by government agencies and organizations in the private and nonprofit sectors, have been a major factor in speeding the application of technology to the extension of science information services. Three broad categories of technology have been applied: micrographics, computers and telecommunications. The use of microforms, particularly microfiche, has allowed the printed science record, especially technical reports, to be compacted, duplicated and distributed inexpensively. Computers allow manipulation of data in machine-readable form to produce outputs tailored to the needs of individual users. Selective dissemination of information, based on a profile of an individual's area of interest, can easily be done for a large number of users with the aid of computers. Finally, telecommunications eliminates the need for individuals to be physically located at the site of an information store. An individual working at a remote terminal can access many data bases in different locations via telecommunication links.

While the application of technology has certainly caused an acceleration of intellectual access to the information store (in that one can locate references to relevant literature much more easily), physical access has not kept pace, since the documents themselves are for the most part not distributed in electronic form, but on paper or microfilm. Documents not available locally must be purchased or obtained through interlibrary loan. One approach to reducing this access time is through the British Library Lending Division (formerly the National Lending Library for Science and Technology), a storage facility which can quickly respond to requests for many hard-to-locate materials.[22] While technologies have certainly allowed the development of services which would not be feasible without them, their role must be put in perspective. As Ziman observes, "For those who enjoy designing and selling mechanical gadgets, this is a fertile field, but the real effort is human: careful, thoughtful classification and indexing in the first place, and a little imagination and knowledge of science in searching for what one wants."[23]

INFORMAL COMMUNICATION

While informal communication among those engaged in scientific activities is as old as science itself, it is only within the last twenty years that these communication processes have been subjected to close scrutiny. Price shows that the "invisible college" phenomenon can be traced back at least to the middle of the seventeenth century. The term appears first to have been applied to that group of scientists which began meeting informally as a club and which eventually formed itself into the Royal Society. Price also points out that the invisible college movement may have received its greatest impetus during World War II with the establishment of teams of scientists to tackle particular problems critical to national security. The invisible college networks of informal communication have been studied by a number of writers, including Crane, Griffith and Miller, Gaston, Mullins, Price and Beaver, and Crawford.[24]

An invisible college is now recognized to be an informal communication network composed of a scientific elite in some specialized research area. The members communicate with each other via telephone, correspondence and professional meetings. They exchange preprints, reprints and drafts of proposals. Crawford points out that information spreads rapidly and efficiently through such a community and likens this spread of information to the spread of infection.

Informal channels of communication play a major role in the diffusion of information on new developments in a field (i.e., on innovation). A considerable amount of research has been conducted on the "diffusion of innovation," particularly in agriculture and medicine. Coleman et al., for example, have demonstrated the great value of a communication network among medical practitioners in the diffusion of drug information.[25] Those doctors well integrated within such a network tend to adopt new drugs much earlier than those less well integrated. At the frontiers of a rapidly changing field, a scientist well integrated within some efficient informal communication network will be at a great advantage over his less integrated colleagues in receiving new information.

Another important and closely related phenomenon is that of the "information gatekeeper," also known as a "technological gatekeeper."

As described by Allen and others, the gatekeeper is an engineer or scientist in an industrial organization to whom others in the organization go when the need for information arises.[26] These individuals make it their business to inform themselves of new developments of concern to the company, both by reading current literature in the field and by maintaining extensive contacts with individuals in other organizations. Although this may not be an officially designated function within the company, the information gatekeeper plays a key role in industrial progress by bringing information into the organization through both formal and informal channels. A similar phenomenon has been shown to exist at national levels. In some countries international technological gatekeepers have been identified. These are scientists or other professionals who stay current with new scientific or technological developments abroad through the literature and professional contacts. In a sense these individuals deal with the import and export of information. For obvious reasons, such individuals would play a particularly valuable role in importing into a developing country the technology of the more industrially advanced nations. The international gatekeeper has been discussed by Allen and others.[27]

Although invisible colleges have been shown to be extremely effective networks for the transmission of information, they do tend to be exclusive rather than inclusive. It may take some years for a younger scientist to develop the necessary contacts to allow him to participate in such a network. Moreover, although there are no absolute political or linguistic barriers, it is much easier for scientists in some countries to participate than it is for others.

Government and technology have influenced, and are influencing, informal communication in much the same way that they have influenced formal communication. Between 1961 and 1967 the National Institutes of Health (NIH) supported a series of experiments in which an attempt was made to "formalize" the informal channels of communication and to extend their influence. The Information Exchange Group experiments established seven information exchange groups in various specialized areas of the biomedical sciences. A leading scientist in the area was appointed as chairman of each group. It was the responsibility of this chairman to see that all scientists in this area of specialization, including scientists outside the United States, were included in the group. NIH provided administrative and secretarial support to facilitate interchange within the group. All communications, however informal or tentative, that a member wished to share with his colleagues were submitted to the group office, duplicated in multiple copies, and distributed to all members of the group. Exchange increased through a "snowball" effect because one communication would stimulate responses from other members. The NIH Information Exchange Groups made a deliberate attempt to widen the invisible college network, bringing in the younger scientists as well as scientists from countries less well developed than those in the West. Although these experiments were controversial (and were bitterly attacked by the editors of some leading science journals), there are many who consider this work the most significant yet to be conducted in the field of scientific communication. Cooper, Heenan and Weeks, and Bever have prepared separate analyses of the benefits of these experiments, and Green presents the very positive views of one of the chairmen.[28] The Information Exchange Groups were shown to have had a very positive effect on research in the fields covered. In many documented cases, the reduced communication lag was shown to have prevented unnecessary duplication of research.

Technology has exerted a profound influence on informal communication, as it has on most other areas of human activity. The most obvious example is the telephone, which can be considered to have had much the same promotional effect on informal communication that the printing press had on formal communication. Technology still has great influence in this sphere. A rather mundane contemporary example is the current CB radio craze. At a more serious level, computer conferencing is beginning to emerge as a major force in communication at a number of levels. As described by Price, for example, computer conferencing has the potential for replacing many types of face-to-face meetings, for substituting for telephone discussions, and even for assuming a major role in the handling of business and other professional "correspondence."[29] "Electronic mail" systems are beginning to appear in U.S. industry, at least on an experimental basis, and great progress with these systems can be expected in the near future.

THE FINDINGS OF USER STUDIES

A considerable number of studies of the information seeking behavior of scientists have been undertaken. Useful bibliographies or reviews of this literature have been prepared by Carter et al., Brittain, Faibisoff and Ely, Faibisoff et al., Barnes, Bates, Davis and Bailey, Ford, Slater, Weinstock et al., and Wood.[30] In addition, this topic is regularly treated in the *Annual Review of Information Science and Technology*.[31]

Wide variations in methodology and in populations studied make it difficult to compare and contrast the findings of the many surveys already conducted. Nevertheless, some findings have occurred with sufficient frequency to allow conclusions to be drawn on information seeking behavior in general. Perhaps the single most important finding is that accessibility (physical, intellectual and psychological) seems to exceed "perceived value" as a factor determining which source will be chosen when the need for information arises. This conclusion is supported by the work of Allen, Gerstberger and Allen, Rosenberg, and Soper, among others.[32] The influence of accessibility on the use of information sources is an obvious manifestation of Zipf's principle of least effort.[33]

Many professionals report an "information overload." They are not looking for more information, but for more efficient ways of receiving and processing information. They stress the need for greater selectivity in information services and for more evaluation, review and synthesis. Annual reviews are highly rated; so are the selection, evaluation and synthesis activities of information analysis centers. Selective Dissemination of Information (SDI) services provide selectivity in output to the user but may lack adequate selection/evaluation in the formation of the data base from which the service is provided.

The need for more rapid access to research results and, more particularly, to information on ongoing research projects is one reason why informal channels of communication are frequently judged more effective than formal channels. The appreciation of the need to make available information on current research (as opposed to research of the recent past) is also manifest in the increasing awareness, on a worldwide scale, of the potential importance of indexes to ongoing research. This is evidenced, for example, by the recent Unesco symposium on this subject.[34]

In many communities the first source consulted when the need for information arises tends to be the personal file of the individual seeking the information. When these files fail, it is quite likely that some informal channel will be turned to. It is only after these sources are exhausted that the scientist or other professional is likely to consider approaching a library or other information center. It is a depressing fact that "going to the library" or "asking the librarian" are actions that are frequently ranked rather low when professionals are asked to list information sources used in a sequence of perceived convenience or perceived value.

SOME PROBLEMS OF THE PRESENT COMMUNICATION CYCLE

There are many problems associated with the dissemination of information through the formal channels depicted in Figure 1, and at least some of these problems are tending to worsen with the passage of time.

One problem is simply that of growth. As science and technology grow, so does the amount of research written, published, distributed, indexed, abstracted, acquired by libraries, and so on. In fact, all of the activities depicted in the cycle must grow at approximately the same rate as science and technology itself. The efficient distribution of results of research and development can be considered as a special form of packaging problem. The number, size and diversity of the packages are constantly increasing. Scientific and technical periodicals are now estimated to number about 50,000 worldwide and the number appears to be increasing at close to a 4 percent compound rate annually. The size of individual periodicals also increases. As one example, Sandoval et al. have pointed out that *Biochimica et Biophysica Acta* has grown at an approximately logarithmic rate since its foundation in 1947.[35] It is now doubling in size approximately every 4.6 years. Growth is not a problem exclusive to the periodical literature. Scientific and technical literature is also increasing rapidly in the form of books, technical reports, patents, standards and other printed forms, and other information is distributed on film, videotape and magnetic tape. Tens of thousands of new technical reports are now released each year in the United States alone.

The secondary literature is forced to grow at approximately the same rate as the primary literature. Again, there is growth in the number of indexing and abstracting services as well as growth in the sizes of these services. Ashworth has demonstrated the latter phenomenon dramatically in terms of the number of years taken by *Chemical Abstracts* to publish successive millions of abstracts: first million — 32 years (1907-1938); second million — 18 years; third million — 8 years; fourth million — 4.75 years; and fifth million — 3.3 years.[36] Clearly this service must soon produce a million abstracts a year to maintain any pretense of keeping up with the growth of the primary literature of potential interest to chemistry and allied fields.

One obvious consequence of this growth is that the literature in any particular subject area tends to become increasingly dispersed and fragmented. This growing scatter increases the problems of special librarians in trying to identify and collect the literature in some subject field; it increases the problems of the secondary services, and above all, it makes it increasingly difficult for the scientist and other professionals to "keep up to date." As Bernal pointed out rather clearly some years ago, the scientist's problem is simply that the literature in his field may be doubling every few years but the time he or she has for reading or scanning this literature remains approximately the same.[37]

The fragmentation of the literature is due to more than growth alone. It is a consequence of increasing specialization in science itself. The splitting up of science disciplines into subdisciplines and these, in turn, into further subdivisions has been referred to as "twigging."[38] While this increasing specialization might be thought of as simplifying the task of keeping current in a field, the situation is not that simple. Scientists may be focusing on smaller and smaller areas of science. At the same time, however, science is becoming more interdisciplinary as groups of investigators deal with problem-oriented research. A scientist may now need to seek information from literature far beyond his field of specialization or academic training.

Because the printing and publishing industry is still largely labor-intensive, the cost of publications has increased and is still increasing at a rate greatly in excess of the rate of inflation in the economy as a whole. The subscription price to some secondary publications, including *Psychological Abstracts* and the *Bibliography of Agriculture,* increased 850 percent in a decade. In 1940 *Chemical Abstracts* could be subscribed to for $12 a year. The 1978 cost is $3500 a year. When the cost of scientific publications increases at a rate much faster than the general rate of inflation in the economy, the effect is to reduce the accessibility of these publications. Many secondary publications have already priced themselves beyond the pocket of the individual and are now found only in libraries. Some are also pricing themselves beyond the resources of the smaller institutions. General accessibility declines as a result.

There is already evidence that the same fate awaits the primary literature of science. Rapidly escalating subscription costs for science journals is causing a gradual but inexorable decline in the proportion of individual to institutional subscribers. De Gennaro has given examples of some of the startling price increases (e.g., *Inorganica Chimica Acta* raised its price to libraries from $26 in 1970 to $235 in 1975) and has pointed out that some science journals have no personal subscribers; they are sold only to institutions.[39]

Dissatisfaction with the science journal as a means of disseminating the results of science research has grown steadily in the last thirty years. It has been suggested that the science journal serves the author well but the reader rather badly. It is an inefficient way of packaging and distributing research results, since the majority of articles published by any one journal a year are unlikely to be of interest to any one subscriber. The present publication and distribution system does not package articles in a way that is most convenient for the scientist as reader. Herschman has suggested that the science journal attempts to fulfill social ("publish or perish"), archival and dissemination roles; it satisfies the first two roles fairly well but is not an adequate dissemination device.[40]

Although the journal literature is growing rapidly, it is not growing fast enough to absorb the increase in research in science itself and in the amount written for publication. In an effort to keep size and price increases within bounds, some publishers are forced to reject manuscripts for reasons of space rather than lack of scientific merit. Authors find themselves competing for publishing space that is growing increasingly scarce and expensive. The submission of a paper to several journals, before eventual acceptance, is becoming more and more common. This increases the average delay between completion of research and the publication of the research results. The science journal must now be considered primarily archival. It certainly does not reflect current scientific research, since it reports work concluded perhaps two years before publication and begun perhaps two years before that. The lag in science publishing is one of the factors that forces increased reliance on informal channels as current awareness sources.

The growth of science and technology in the developing nations creates another problem: a proliferation in the number of languages in which significant research results are published. It seems reasonable to expect that Chinese will eventually emerge as a major language in many fields of science. It also seems likely that other languages, insignificant in science communication in the past, will assume much greater importance. To take one example, Portuguese may become a major language of publication as more Brazilian scientists begin to publish in their own national journals rather than in those of other countries. The languages of the developing countries are likely to be particularly important in a small number of research areas such as tropical medicine and tropical agriculture.

One final problem is worth mentioning. Science communication is no longer concerned exclusively with transfer of information from scientist to scientist. The transfer of results of scientific research to the practitioner (e.g., in industry and agriculture) is assuming greater significance. So is the matter of "vulgarization" — informing the "man in the street" of science progress and accounting for that part of the tax dollar which is consumed by scientific research. A related problem is that of the need to transfer to the developing countries the benefits of research conducted in the developed nations. These are all very special communication problems requiring "repackaging" of research results, translation from scientific to more popular terminology, special-purpose journals, alternative communication media, and various types of "extension agent" to carry the benefits of science into the fields, the factories, the hospitals, and other application environments.

THE FUTURE

Having dwelt rather heavily on the problems of the present communication cycle, it should also be clear that considerable progress has been made in various aspects of science communication in the last decade. The most notable causes of this progress have been the application of computers to the publication of secondary services, the resulting proliferation of machine-readable data bases, and the rapid growth of on-line systems to make these data bases accessible. It seems almost certain that future achievements must also result from further application of automation throughout the communication cycle.

Lancaster has suggested that society is in the process of evolving away from formal communication patterns which for centuries have been based almost exclusively on print on paper to a communication system which will be largely paperless (i.e., electronic).[41] He suggests that currently an interim stage in this evolutionary process exists, a stage in which the computer is used to produce print-on-paper publications. The distribution of information is still achieved through traditional methods. Machine-readable data bases exist side by side with data bases in printed form but have not yet replaced them. It is likely that the replacement phase will begin very soon. In step with similar developments in other segments of society, where electronic processing will largely substitute for the shuffling of paper, machine-readable data bases can be expected to replace many institutions that have been taken for granted as existing forever in print-on-paper form. Undoubtedly the secondary publications will be the first to go. Somewhat later the science journals will probably be replaced by the on-line composition, distribution and exploitation of reports of science research. Many types of reference books will also give way to electronic data banks. In fact, it seems only a matter of time before the entire communication cycle operates in a largely electronic mode. What will be the role of research libraries in the electronic society? Will they serve only as archival repositories of the literature of the past? Or will they still have important functions to perform as publicly accessible entries into a universe of electronic resources? And what of librarians? What role will they play in this society? What skills will they need? Will the proliferation of on-line terminals, and the information resources that can be accessed through these devices, render librarians redundant? Or will the librarian emerge as an indispensable and respected exploiter of a vast electronic "library without walls"?

References

1. Price, Derek J. de Solla. *Little Science, Big Science.* New York, Columbia University Press, 1963.

2. King, D.W., et al. *Statistical Indicators of Scientific and Technical Communication (1960-1980); A Research Report.* Rockville, Md., King Research, Inc., 1976, vol. 2, p. 49.

3. United Nations Educational, Scientific and Cultural Organization. *Statistical Yearbook 1968.* Paris, Unesco, 1969, p. 384; ________. *Statistical Yearbook 1976.* Paris, Unesco, 1977, p. 632.

4. National Science Board. *Science Indicators 1974.* Washington, D.C., National Science Foundation, 1975, p. 2.

5. Grogan, Denis. *Science and Technology: An Introduction to the Literature.* 3d ed. rev. Hamden, Conn., Linnet Books, 1976.

6. Thornton, John L., and Tully, R.I.J. *Scientific Books, Libraries and Collectors: A Study of Bibliography and the Book Trade in Relation to Science.* 3d ed. rev. London, Library Association, 1971.

7. Kronick, David A. *A History of Scientific and Technical Periodicals: The Origins and Development of the Scientific and Technical Press, 1665-1790.* 2d ed. Metuchen, N.J., Scarecrow Press, 1976.

8. Manzer, Bruce M. *The Abstract Journal, 1790-1920: Origin, Development and Diffusion.* Metuchen, N.J., Scarecrow Press, 1977.

9. Auger, Charles P., ed. *Use of Reports Literature.* London, Butterworths, 1975.

10. Luedke, James A., Jr., et al. "Numerical Data Bases and Systems," *Annual Review of Information Science and Technology* 12:119-81, 1977.

11. Hersey, David F., and Lakamp, David W. "Approaching the Problem of Current Research Awareness," *Nachrichten für Dokumentation* 26:113-17, 1975.

12. Jones, Colin. "The TECHNOTEC Data Base and Technology Exchange Service of Control Data," *Program* 11:94-100, July 1977.

13. Christianson, Elin B. "Special Libraries: Putting Knowledge to Work," *Library Trends* 25:399-416, July 1976.

14. Kruzas, Anthony Thomas. *Business and Industrial Libraries in the United States, 1820-1940.* New York, Special Libraries Association, 1965; and Marshall, Margaret R. "British Industrial Libraries Before 1939," *Journal of Documentation* 28:107-21, June 1972.

15. Kruzas, ibid., p. 87.

16. Algermissen, Virginia. "Biomedical Librarians in a Patient Care Setting at the University of Missouri-Kansas City School of Medicine," *Bulletin of the Medical Library Association* 62:354-58, Oct. 1974; and Colaianni, Lois Ann. "Clinical Medical Librarians in a Private Teaching-Hospital Setting," *Bulletin of the Medical Library Association* 63:410-11, Oct. 1975.

17. Scarfe, David. "The Future Pattern of Information Services for Industry and Commerce," *Aslib Proceedings* 27:80-89, March 1975.

18. Adkinson, Burton W. "Federal Government's Support of Information Activities: A Historical Sketch," *Bulletin of the American Society for Information Science* 2:24-26, March 1976.

19. Harvey, Joan M. *Specialised Information Centres.* Hamden, Conn., Linnet Books, 1976.

20. Weisman, Herman M. *Information Systems, Services and Centers.* New York, Becker and Hayes, 1972.

21. U.S. National Science Foundation. *Federal Scientific and Technical Communication Activities—1976.* Washington, D.C., USGPO, Oct. 1977. (PB 272 800)

22. Houghton, Bernard. *Out of the Dinosaurs: The Evolution of the National Lending Library for Science and Technology.* Hamden, Conn., Linnet Books, 1972.

23. Ziman, John. *The Force of Knowledge: The Scientific Dimension of Society.* Cambridge, Cambridge University Press, 1976, p. 108.

24. Crane, Diana. *Invisible Colleges: Diffusion of Knowledge in Scientific Communities.* Chicago, University of Chicago Press, 1972; Griffith, Belver C., and Miller, A. James. "Networks of Informal Communication Among Scientifically Productive Scientists." *In* Carnot E. Nelson and Donald K. Pollock, eds. *Communication Among Scientists and Engineers.* Lexington, Mass., D.C. Heath, 1970, pp. 125-40; Gaston, Jerry C. *Originality and Competition in Science: A Study of the British High Energy Physics Community.* Chicago, University of Chicago Press, 1973; Mullins, Nicholas C. "The Distribution of Social and Cultural Properties in Informal Communication Networks Among Biological Scientists," *American Sociological Review* 33:786-97, Oct. 1968; Price, Derek J. de Solla, and Beaver, Donald deB. "Collaboration in an Invisible College," *American Psychologist* 21:1011-18, Nov. 1966; and Crawford, Susan. "Informal Communication Among Scientists in Sleep Research," *Journal of the American Society for Information Science* 22:301-10, Sept.-Oct. 1971.

25. Coleman, J.S., et al. *Medical Innovation: A Diffusion Study.* Indianapolis, Bobbs-Merrill, 1966.

26. Allen, Thomas J. "Organizational Aspects of Information Flow in Technology," *Aslib Proceedings* 20:433-54, Nov. 1968; ________, and Cohen, Stephen I. "Information Flow in Research and Development Laboratories," *Administrative Science Quarterly* 14:12-19, March 1969; and Allen, Thomas J., et al. *The Problem of Internal Consulting in Research and Development Organizations* (Sloan School of Management Paper No. 319-68). Cambridge, Massachusetts Institute of Technology, Sloan School of Management, 1968.

27. ________. "The International Technological Gatekeeper," *Technology Review* 73:36-43, March 1971; Allen, Thomas J., and Cooney, Stephen. "Institutional Roles in Technology Transfer: A Diagnosis of the Situation in One Small Country," *R & D Management* 4:41-51, Oct. 1973; and ________. "The Technological Gatekeeper and Policies for National and International Transfer of Information," *R & D Management* 5:29-33, Oct. 1974.

28. Cooper, Marianne. "Current Information Dissemination: Ideas and Practices," *Journal of Chemical Documentation* 8:207-18, Nov. 1968; Heenan, W.F., and Weeks, D.C. *Informal Communication Among Scientists* (George Washington University Biological Sciences Communication Project). Washington, D.C., George Washington University, 1971; Bever, Arley T. "The Duality of Quick and Archival Communication," *Journal of Chemical Documentation* 9:3-6, Feb. 1969; and Green, David. "Death of an Experiment," *International Science and Technology* 65:82-88, May 1967.

29. Price, Charlton R. "Conferencing via Computer: Cost Effective Communication for the Era of Forced Choice." *In* Harold A. Linstone and Murray Turoff, eds. *The Delphi Method: Techniques and Applications.* Reading, Mass., Addison-Wesley, 1975, pp. 497-516.

30. Carter, Launor F., et al. *National Document-Handling Systems for Science and Technology.* New York, John Wiley & Sons, 1967; Brittain, John Michael. *Information and Its Users: A Review with Special Reference to the Social Sciences.* Bath, England, Bath University Press, 1970; Faibisoff, Sylvia G., and Ely, Donald P. "Information and Information Needs," *Information Reports and Bibliographies* 5:2-16, 1976; Faibisoff, Sylvia G., et al. *An Introduction to Information and Information Needs: Comments and Readings.* Syracuse, N.Y., Center for the Study of Information and Education, Syracuse University, 1973; Barnes, R.C.M. "Information Use Studies: Part 2 — Comparison of Some Recent Surveys," *Journal of Documentation* 21:169-76, Sept. 1965; Bates, Marcia J. "User Studies: A Review for Librarians and Information Scientists." Bethesda, Md., ERIC Office of Education, 1971. (ED 047 738); Davis, Richard A., and Bailey, Catherine A. *Bibliography of Use Studies.* Philadelphia, Drexel Institute of Technology, Graduate School of Library Science, 1964; Ford, Geoffrey. "Progress in Documentation: Research in User Behaviour in University Libraries," *Journal of Documentation* 29:85-106, March 1973; Slater, M. "User and Library Surveys." *In* H.A. Whatley, ed. *British Librarianship and Information Science, 1966-1970.* London, Library Assoc., 1972, pp. 232-56; "User Practices Based on a Review of User Studies." *In* Melvin J. Weinstock, et al. *A Recommended Design for the United States Medical Library and Information System.* Washington, D.C., Herner and Co., Jan. 1966, vol. 2, chap. V, pp. 1-56. (PB 172 924); and Wood, D.N. "User Studies: A Review of the Literature from 1966-1970," *Aslib Proceedings* 23:11-23, Jan. 1971.

31. *Annual Review of Information Science and Technology.* Martha E. Williams, ed. Knowledge Industry Publications, 2 Corporate Park Dr., White Plains, N.Y. 10604. 1966- .

32. Allen, Thomas J. *The Use of Information Channels in Research and Development Proposal Preparation* (Sloan School of Management Paper No. 97-64). Cambridge, Massachusetts Institute of Technology, Sloan School of Management, 1964; Gerstberger, Peter G., and ———. "Criteria Used by Research and Development Engineers in the Selection of an Information Source," *Journal of Applied Psychology* 52:272-79, Aug. 1968; Rosenberg, Victor. *The Application of Psychometric Techniques to Determine the Attitudes of Individuals Toward Information Seeking.* Bethlehem, Penna., Center for the Information Sciences, Lehigh University, 1966; and Soper, Mary Ellen. "The Relationships Between Personal Collections and the Selection of Cited References." Ph.D. diss., University of Illinois Graduate School of Library Science, Urbana, 1972.

33. Zipf, George Kingsley. *Human Behavior and the Principle of Least Effort; An Introduction to Human Ecology.* Cambridge, Mass., Addison-Wesley, 1949.

34. United Nations Educational, Scientific and Cultural Organization. *UNISIST International Symposium on Information Systems and Services in Ongoing Research in Science* (Proceedings, Paris, 1975). Budapest, Hungarian Central Technical Library and Documentation Centre, 1976.

35. Sandoval, A.M., et al. "The Vehicles of the Results of Latin American Research: A Bibliometric Approach." Paper presented at the 38th World Congress of Federacion Internacional de Documentacion, Mexico City, 1976.

36. Ashworth, Wilfred. "The Information Explosion," *Library Association Record* 76:63-68, April 1974.

37. Bernal, J.D. "The Transmission of Scientific Information: A User's Analysis." *In* National Science Foundation. *Proceedings of the International Conference on Scientific Information* (Washington, D.C., Nov. 16-21, 1958). Washington, D.C., National Academy of Sciences, National Research Council, 1959, vol. 1, pp. 77-95.

38. *See, for example,* Vinken, Pierre J. "Developments in Scientific Documentation in the Long Term," *JASIS* 25:109-12, March-April 1974.

39. De Gennaro, Richard. "Escalating Journal Prices: Time to Fight Back," *American Libraries* 8:69-74, Feb. 1977.

40. Herschman, Arthur. "The Primary Journal: Past, Present, and Future," *Journal of Chemical Documentation* 10:37-42, Feb. 1970.

41. Lancaster, F.W. *Toward Paperless Information Systems.* New York, Academic Press, 1978.